FIRE AND HARVEST RESIDUAL (FAHR) PROJECT:

The Impact of Wildfire and Harvest Residuals on Forest Structure and Biodiversity in Aspen-Dominated Boreal Forests of Alberta

FINAL SUMMARY REPORT

Prepared for: Alberta Environment

Prepared by: Alberta Research Council

September 1, 1999

ISBN No. 0-7785-0919-2

Pub. No. T/495

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Time Frame of Project Covered by this Report:

April/95-March/99

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GENERAL ACKNOWLEDGEMENTS

This project has required and received strong commitments from government, the forest industry and academia.

We recognize the strong administrative and funding support provided by the Alberta Research Council. Special thanks are extended to Malcolm Wilson, Jack Nolan, Dave McNabb, Richard Johnson, Ahrlene Hrynyk, Fabian Harrison, Gerry Lofthaug, Duane Nakonechny, Pat Soldan, Elaine Cannan, Debby Franchuk, Sonia Hunka, Nancy Fraser Hrynyk, Connie Jackson, Val Golka, Lorraine Robert, Susan Stecyk, Brenda Dziwenka, Patricia Ferleyko, and Kathy Ilkiw for their assistance.

We thank our technical staff for their hard work in the field and input during analysis and publication of this document. These technicians include Len Peleshok, Kelly Sturgess, Elizabeth Joyce, David McKinnon, Stephen Hanus, Kristi Anderson, Laura Blonski, Selena Cole, Brenda Dew, Cris Gray, Carrie Melanson, Lindsay Tomyn, and Ross Warren.

Critical to the completion of the research was the funding provided by Alberta Environment (AENV). We are particularly indebted to AENV's Sustainable Forest Management Research Users Group: Harry Stelfox, Cam MacGregor, Ken Crutchfield, Cal Webb, Ted Szabo, Dan Chambers, and Peter Lee. We are also grateful for the support of Dennis Quintilio, Forest Management Division, Land and Forest Service and Bob Andrews, Wildlife Management Division, Natural Resources Service. The Wildlife Management Enhancement Program of the Alberta Conservation Association also provided financial assistance. We would like to thank Doug Culbert and Dave Park for their assistance in administering those funds.

Our primary industrial partner was Alberta-Pacific Forest Industries, which provided significant logistical and financial support for the project. Many of the concepts dealing with stand structure in this report are based on the harvesting principles practiced by Alberta-Pacific Forest Industries. In particular, we would like to thank Daryl Hebert, Shawn Wasel, Stan Boutin, Brydon Ward, Andy Nigel, Bob Nichol, Karl Larsen, and Kari Stuart-Smith. Daishowa-Marubeni International Forest Products also provided funding and we would like to thank Bob Wynes and Frank Oberle. Special thanks goes to Brad Stelfox of FOREM Consulting whose initial input and support helped pave the way for this project.

A number of researchers provided advice and constructive criticisms of the project. Special thanks go to Dr. Susan Hannon (University of Alberta), Dr. Fred Bunnell (University of British Columbia), Dr. Steve Cummings (University of Alberta), and Dr. Dan Farr (Foothills Model Forest).

The study would not have been logistically feasible without the support of the field staff of Alberta Environment's Land and Forest Service. In particular, we would like to thank Al Hoven, Karen McNeil, Dale Huberdeau, Paul Steiestol, Barry Onysty, Wayne Becker, and Leo Forseille.

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EXECUTIVE SUMMARY

The Fire and Harvest Residual Project compares the early successional trajectories for forest structure and biodiversity between wildfire- and harvest-origin aspen-dominated stands within northcentral Alberta. This retrospective study compared the most common wildfire residual pattern (<1% live merchantable timber) to a harvest strategy leaving 5-6% live merchantable timber over the first 28 years of succession.

Key Findings

1. **The greatest difference between wildfire and harvest stands occurs immediately after disturbance.** Any differences in forest structure or biodiversity noted in this study were greatest immediately after disturbance. These were the result of the very different processes involved with wildfire and harvest.

2. **Snags, downed wood, understory plant, mammal, and bird communities converged in the first 28 years.** Despite very disparate differences immediately after disturbance, forest structures and biotic communities from wildfire and harvest stands exhibited significant convergence during the first 28 years. Biological legacies associated with disturbance diminished. Stand development was increasingly set by the cohort of regenerating trees, with structure and biota becoming more similar between disturbance types.

3. **Differences after 28 years of succession were largely restricted to the relative abundances rather than the presence or absence of species.** Although few plant and animal communities were identical between wildfire- and harvest-origin stands after 28 years. The differences were at the level of relative species abundance, rather than the presence/absence of species. This result notwithstanding, it is important to note that the study only assessed common species. Rare species may have somewhat different thresholds of response to disturbances and subsequent recovery.

4. **The removal of carbon from harvest stands manifests itself as a loss of snags, then downed logs, and eventually in a lower carbon content within the soil organic layer.** One clear difference between wildfire and harvest stands was the removal of carbon from harvested stands. In comparison, wildfire stands lost carbon through consumption of the forest floor. However, the retention of most standing materials provided a source of carbon unavailable in harvest stands. Given the relatively short rotation of aspen harvest, it was unclear whether harvest stands will

accrue pre-disturbance levels of carbon prior to the next rotation.

5. **Early fire communities are unique and cannot be replicated by any practical harvest plan.** An unexpected result of the present study was the uniqueness of early wildfire communities. Plant and animal communities present immediately post-fire were very different from all other communities. It is unlikely that any economically feasible plan for leaving harvest residuals will replicate this community.

__Management Implications__

1. **Retention of trees at harvest provides a continuing source of advanced forest structure for future stand development.** The convergence of wildfire and harvest stands was due, in part, to the continued growth of trees left at harvest and their eventual death and decay. Retention of a continuous distribution of tree sizes, including pulp-merchantable diameters, allowed for a relatively constant recruitment of large tree and deadwood resources post harvest.

2. **Increasing the amount and patch size of residuals leads to more old stand attributes.** This study examined the impact of leaving 6% residuals at the point of harvest. It did not directly investigate the impact of leaving varying amounts of live residuals. The logic of our results and correlations with other studies suggested that leaving more live residuals tended to speed the convergence between wildfire and harvest stands and provide some older seral stage habitats. However, there is a limit to the amount that should be left behind since a very large amount of live residuals tends to suppress aspen regeneration. With convergence partially dependent on the regeneration of trees, leaving too many residuals may delay convergence by hindering regeneration.

The spatial pattern of materials left on the block also affects biota. Larger patches of materials retain more of the biodiversity found in the pre-cut stand. Nonetheless, this should not preclude the use of smaller patches. For any set level of retention, one can place a greater number of smaller patches throughout the block. Even though smaller patches have less initial impact, these patches may eventually provide a wider dispersal of old growth communities throughout the block in comparison to a few large patches. In general, a variety of patch sizes distributed over the cutblock may be appropriate for most harvest areas.

3. **Harvest potentially leads to a reduction of deadwood resources and soil carbon with an ensuing decline in biodiversity.** As with other forested ecosystems, deadwood resources are a significant feature in aspen-dominated boreal forests. Our results indicated that even with a 5-6% residual, there was a potential reduction of deadwood and soil carbon. Although losses within a single rotation may be relatively small, those losses may compound over successive cycles of harvest and regeneration.

   Since losses may accrue with time, maintenance of deadwood resources is a potential long-term management issue. Clearly, it will be difficult to compensate for all the carbon removed from harvested stands. However, we may be able to extend the rotations on a percentage of stands and develop regional strategies that provide a base level of snags, DWM, and soil carbon over broad areas.

4. **Maintenance of wildfire communities requires some protection from salvage logging.** A percentage of mature or old stands burned in wildfires should be allowed to escape salvage harvesting. This would ensure the perpetuation of the very unique fire-dependent aspen community in Alberta. These stands would not have to be "protected" in perpetuity, rather 15-20 years would be adequate. Currently, burned stands escape harvest by happenstance rather than design. A clear policy should be crafted to set aside a percentage of the landbase that burns. To be of value, the unsalvaged stands should be large and mature- or old-aged at the time of disturbance. A policy of high residual salvaging should not be substituted for setting aside whole stands.

5. **Careful assessment of management issues should precede selection of traditional research, adaptive management, or status monitoring as the appropriate knowledge gathering platform.** This project identified a number of gaps in the knowledge base and areas of management concern. These included further work on understanding functional relationships between residuals and different taxonomic groups, integration of different cutblock residuals, and long-term losses in large tree and deadwood resources.

   We recognized that a number of knowledge gathering techniques are available for dealing with these issues. Objectives, scope, spatial and temporal scale, cause-effect relationships, and use of deliverables should be carefully assessed prior to decisions on the use of traditional research, adaptive management, or status monitoring models.

1.0 ECOSYSTEM MANAGEMENT AND THIS PROJECT

Philip Lee

One of the greatest challenges to integrated land management in Alberta is the relatively recent large-volume harvest of trembling aspen (*Populus tremuloides* Michx). This land use expansion was implemented to strengthen the forest industry and diversify the economic base of communities situated in Alberta's aspen and mixedwood forests. To meet the challenge of managing for such a large-scale change in land use, Alberta has embarked on an ecosystem approach to the management of natural lands.

Ecosystem management is a philosophy rather than a specific set of management practices. Its goals are the protection and enhancement of ecosystem integrity and functions over wide spatial and temporal scales (Lorimer & Frelich 1994; Irland 1994). These goals are accomplished by a series of logical steps that build on the knowledge and practices of the past, rather than a radical shift from present methods. However, ecosystem management is an on-going process that responds to changes in science and technology, as well as economic and societal values. Furthermore, ecosystem management practices are regionally tailored to a specific ecosystem and local objectives. The role of research and science in ecosystem management is to ascertain the range of economic and societal values, which may be sustained by an ecosystem.

Two schools of thought dominate ecosystem management. At one extreme are management strategies that explicitly maintain combinations of known values (e.g. timber supply, endangered species, consumptive species, water quality). These strategies, known as "fine-filter" approaches (Hunter 1991), revolve around management of relatively few values, emphasizing a high degree of prior knowledge of ecosystem patterns and processes. At the other end of the spectrum are coarse-filter approaches that emphasize protection and maintenance of whole ecosystem processes (Salwasser 1994). These strategies are appropriate when our knowledge base of species requirements and ecosystem patterns and processes are poor (Cissel et al. 1994). In part, coarse-filter approaches assume that species, and ecosystem patterns and processes, have an underlying natural variation. Species are adapted and ecosystems are resilient to changes over this range of temporal and spatial variation in the landscape. The probability of species survival or ecosystem recovery decreases if disturbances are outside its natural range. Furthermore, managing within the bounds of natural variability provides the greatest flexibility for incorporating new knowledge and changing economic and societal values.

Ecological management has spawned a number of large-scale ecosystem studies that have been, or are being, conducted within Alberta's aspen-dominated mixedwood forests e.g. Aspen Biodiversity Project (Stelfox 1995), Forest Fragmentation Project (Hannon et al. 1994), Terrestrial Riparian Organisms Lakes and Streams (TROLS) (Prepas et al. 1999), Landscape Structure and Biodiversity (Hannon 1999), Residual Project (Schieck et al. 1999), and EMEND project (Spence et al. 1999). These studies along with the Fire and Harvest Residual project address the management of both ecosystem processes and species. The broader goals of ecosystem management are to produce a mix of targeted values imbedded with a coarse-filter management approach (Anon. 1992; Covington et al. 1994).

The mix of fine and coarse-filter approaches depends, in part, on the ability to use natural patterns of disturbance as templates for man-made disturbances. Although a coarse-filter approach may mitigate many of the impacts of resource use, it is impossible to replicate all disturbance parameters with management practices. The differences between man-made and natural disturbances are likely to be greatest immediately after disturbance. As both types of systems recover, these differences may decrease. If man-made disturbances have not fundamentally altered the ecosystems, then eventually these ecosystems may converge in structure, composition, and function. One potential measure of harvest impact is the similarity between naturally disturbed and harvest stands.

For ecosystem management to be successful, monitoring techniques need to be developed that assess our successes and failures so that management practices can be adjusted accordingly. By its very nature, ecosystem management will not optimize the quantities of any single element (e.g. timber supply, recreational activities, biodiversity) (Salwasser 1994). Thus, monitoring the abundance of any single element can be misleading. We should develop a wide and representative set of indicators. These indicators should respond to forest structures or disturbance parameters. Logically, these indicators should be compared with similar indicators in post-disturbance and natural ecosystems.

This project addresses the need for a basic understanding of natural disturbances and succession within the aspen-dominated boreal forests of Alberta and their application to timber harvest. It uses a coarse-filter approach by examining the impact of wildfire and harvest residuals on soils, forest structure, and wildlife. We fully expect dramatic differences immediately after harvest. The question, then, is whether the structure and function of harvest stands eventually converge with wildfire stands and over what time period. In examining a broad base of forest and biodiversity elements,

the project will identify potential indicators for ecosystem management.

Project Rationale

In boreal forest, the primary natural stand-replacing disturbance is wildfire (Rowe & Scotter 1973). However, man-made fragmentation of the landscape and active fire suppression have led to an overall decrease in wildfires throughout northcentral Alberta (Murphy 1987; Larsen 1989; Cumming 1997). Like wildfires, timber harvest is a large-scale, stand-replacing disturbance on the landscape and with decreasing wildfires, it will increasingly become the primary disturbance type. Some have suggested that wildfire disturbance patterns could be used as a guide to understanding the resilience, recovery, and sustainability of forests affected by timber harvest (Wright 1974; Hunter 1993; Attiwill 1994). Hunter (1993) argues that three harvest parameters roughly parallel parameters in wildfires. These parameters are:

fire intensity = post-harvest residuals
fire frequency = rotation age
stand size = cutblock size

This project deals with the first of these parameters, residuals remaining after wildfires and harvest. The term "biological legacies" describes the effect of residual materials left after disturbances (North & Franklin 1990; Franklin 1993). In the boreal forest, all the elements of the intact pre-fire forest may be found as residual materials post-wildfire. These include trees, snags, downed woody materials, shrubs, herbs, cryptograms, and soils. Residual materials vary over the post-wildfire landscape from single isolated elements to large-scale "stringers" or "fire-skips". The latter can encompass several square meters to hundreds of hectares potentially forming a significant portion of the area affected in large fires (Eberhart & Woodard 1987).

These legacies can be detected for a number of years in older stands. Lee et al. (1997) demonstrated that >50% of snags and >75% downed woody materials in aspen-dominated stands 20-30 years of age were derived from the pre-wildfire material. In a cooperative study, Schieck et al. (1995) suggests that some bird species traditionally associated with old stands (>120 years) were abundant in the young stands (20-30 years) that retained high densities of residual materials.

Timber harvest has the potential to reproduce many of the post-fire patterns and maintain variability over the landscape. Elements such as trees, snags, downed woody materials and understory plants can be retained within cutblocks, leaving a mosaic of disturbed and undisturbed areas over the landscape. Current operating ground rules restrict the amounts and types of residual materials left within cutblocks. However, these regulations are under review.

To support changes in operating ground rules, data is required on the amounts and types of residuals to be left on cutblocks. Using wildfires as a template to increase the variability of residuals within cutblocks seems a logical strategy. To implement this approach we need to answer the following question:

<u>Question 1</u>

What are the stand-level similarities and differences in the types and quantities of residual materials left by wildfire and timber harvest?

This project will describe and analyze the patterns of residuals in wildfire and harvest stands. These results will provide a baseline for using wildfires as a template for timber harvest at the stand level.

Residual materials left after disturbances may provide critical habitats for wildlife, such as foraging areas (Flack 1976), nesting sites (Hansen et al. 1995), travel corridors (Miller & Getz 1973), shelter and cover areas (Barclay et al. 1988), and seed sources for plants (Ranney et al. 1981). Currently, there is relatively little data on how species within aspen-dominated boreal forests utilize residuals. To fully understand the role of residuals in shaping the post-wildfire community and then to develop strategies for harvest communities, we must understand the relationships between residual structures and biodiversity. This leads to our second question:

<u>Question 2</u>

How do residuals (e.g. trees, snags, DWM) function as critical habitat for plants and animals within wildfire and harvest stands?

This project incorporates a series of forest structure and biodiversity subprojects (details to follow) that focus on the dispersion of species/communities within wildfire and harvest stands. These studies will identify characteristics of residuals that serve as habitat in post-wildfire and post-harvest stands.

Even with the use of variable harvest patterns and alternative prescriptions, there still exist differences between wildfire and harvest stands. These differences are likely to be greatest immediately after disturbance. However, residuals decrease with increasing stand age and are increasingly replaced by elements from the post-disturbance stand (Harmon et al. 1986; Spies and Franklin 1988). As an example, pre-fire origin snags form only 5.2% of snags within mature aspen stands (50 to 60 years) compared to 50% of snags in young stands (20 to 30 years) (Lee et al. 1997). Initial differences, rates of residual structure degradation, and development of structures within post-disturbance stands, all play significant roles in determining whether timber harvest and wildfire stands converge.

The gap between wildfire and harvest stands should indicate the degree of success in integrating a coarse-filter approach. In particular, the time for wildfire and harvest stands and landscapes to converge is a potentially useful measure for evaluating the relative success (short-term) of ecosystem management. If convergence takes a relatively short period, then harvest prescriptions are likely to be relatively successful in maintaining natural post-disturbance communities. To monitor, evaluate, and change our prescriptions, we need to compare the development of wildfire and harvest stands through time. This leads to the last question:

Question 3

What are the short-term successional trajectories for residual material and associated wildlife in wildfire and harvest stands?

We will measure residual materials (trees, snags, downed woody materials, understory herbs, shrubs, saplings, and soils) and evaluate changes within a chronosequence of wildfire and harvest stands. In addition, we will link early development of wildfire and harvest stands with successional changes in plant and animal communities.

This project complements the EMEND project (ecosystem management emulating natural disturbance project) (Spence et al. 1999). EMEND compares a series of harvested and prescribed burn plots (10 ha). Plots will be treated with varying amounts of residuals (0-70%) and monitored on an ongoing basis. FAHR and EMEND projects have different spatial scales, focus organisms, and time frames.

In summary, this project addresses three major issues that are critical for linking timber harvest patterns to wildfire landscapes. We will: (i) evaluate differences in soils and forest structure between wildfire and harvest stands, (ii) evaluate use of wildfire and harvest residuals by plants and animals, and (iii) evaluate the degree to which wildfire and harvest stands converge in the first 28 years after disturbance. To carry out such a study, we required an inter-disciplinary team of scientists to work in the same field sites. In particular, a high degree of interaction among soil, plant, and animal ecologists was needed to link changes in biodiversity to changes in stand development.

This document contains the abstracts for each of the subprojects. Full length papers and descriptions of the research are available from the authors. The prohibitive length of the document and potential copyright infractions with previously published materials prevents their publication in this document.

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2.0 GENERAL EXPERIMENTAL DESIGN

Philip Lee

General Biophysical Description

Study sites were located in the Central Mixedwood natural sub-region of the Boreal Forest natural region (Alberta Environmental Protection 1994). The study stands and sites were located in an area bounded by Red Earth, Slave Lake, Mariana Lakes, and Horse Creek. Typical mean summer (May - August) temperatures range from 7.0 to 20.4°C with a mean of approximately 13.5°C, winter temperatures (November - February) range from -7.7 to -18.6°C with a mean of -13.2°C. Approximately, 240 mm and 64 mm of precipitation fall in the summer and winter, respectively. Eutric brunisols and grey luvisols were the soil types over all study sites. Sites were dominated by trembling aspen (*Populus tremuloides* Michx.) with balsam poplar (*P. balsamifera* L.), paper birch (*Betula papyrifera* Marsh.), white spruce (*Picea glauca* Moench.), and balsam fir (*Abies balsamea* L.) occurring as secondary species.

Selection of Study Stands

Preliminary queries of the Alberta Provincial Forest Fire Centre records indicated there have been more than 27 000 fires recorded from 1961 to 1993. Most of the fires located east of the Peace River were initiated in pine or black spruce stands but moved to other stand types. Fires initiated in pure aspen or pure white spruce were few and relatively small. In terms of area burned, black spruce forest was the greatest and mixedwoods were second (based on data from 1983 to 1993). These analyses indicate that wildfire was a significant stand replacing disturbance for mixedwood stands.

Wildfires were selected as potential candidates for the study based on fire map overlays of the Alberta Phase 3 Inventory Data (Alberta Forestry, Lands and Wildlife 1985). A search resulted in 286 fires within our study area of suitable size and composition. Of these wildfires, 61 had burned through at least one 30-ha. aspen-dominated patch. Aerial photos of each patch were examined to evaluate 1) whether the Phase III information had classified the patch correctly, and 2) whether the wildfire was stand-replacing (i.e. >95% of trees dead). Based on air photo interpretation, approximately 100 stands were selected as potential sites for our study. These stands were ground truthed to verify our aerial photograph interpretation and to determine human disturbance. Based on the ground truthing, we identified stands in each of three age categories (Table 1). Each of the wildfire stands were currently aspen-dominated

with the pre-disturbance state of 20-50% conifer, little human disturbance, similarity to other study stands, and road access considerations. All stands were a minimum of 35 ha. to reduce edge effects. Stand records indicated tree basal area of 32 to 34 m^2 per ha.

Recent harvest activity of aspen-dominated stands has resulted in many available one-year-old stands. Sites with 5-6% residual live merchantable trees were chosen as a common retention practice worth investigating. We found seventeen fourteen-year-old and five twenty-eight-year-old, aspen-dominated harvest cutblocks within 100 km of Slave Lake. These potential sites were ground-truthed to verify our aerial photograph interpretation and to assess human disturbance. We selected three stands in each of the three age categories. Choice of both wildfire and harvest sites and stands were restricted to those stands originating from wildfire >100 years ago. These are the stand ages currently being harvested in Alberta.

Experimental Design

The experimental design compares wildfire and harvested sites or stands at three time intervals after disturbance (Table 1). Depending upon the spatial scale and ecology of the process or organism, the design featured sites (1 ha) or stands (>35 ha) as replicates. Preliminary analysis indicated that stands and sites change rapidly after disturbance. For this reason, it was important to stratify rigorously for age. Stands and sites were aged one, fourteen, or twenty-eight years at the beginning of the experiment. As the experiment progressed over the four years of study, stands and sites aged, but stayed within the same age class (Table 1). The core subprojects focused on stand-level sampling. Within each stand, we randomly placed ten 100 x 100 m sites (1 ha). Each stand had a 50 m buffer from adjacent stands. A permanent marker was placed at the center of each site. A number of the sub-projects made modifications to the overall experimental design. In particular, some subprojects increased the number of stands sampled per stand age or incorporated older stands in the design. The study was initiated April 1995 and completed March 1999.

References

Alberta Environmental Protection. 1994. Natural regions and subregions of Alberta: summary. Alberta Environmental Protection. Edmonton, Alberta. Publication No. I/531. 18 pp.

Table 1 Experimental design for the core field projects. Stands or sites within an age class had identical ages at the beginning of the experiment. Ages increased over the four years of the experiment creating the range of age classes. Depending upon the year measurements were taken, they may be reported as values within these ranges.

	Time Since Disturbance (years)		
Disturbance Type	1-4	14-18	28-32
Wildfire	3 stands (30 sites)	3 stands (30 sites)	3 stands (30 sites)
Harvest	3 stands (30 sites)	3 stands (30 sites)	3 stands (30 sites)

3.0 OVERSTORY COMPOSITION AND SPATIAL DISTRIBUTION OF LIVE RESIDUAL MATERIAL IN LANDSCAPES AFFECTED BY FIRE

Cheryl Smyth, Mark Dale and Philip Lee

Abstract

Twenty fires within northern Alberta, ranging in size from 77 to 5766 hectares were studied to determine whether a relationship exists between the distribution of live residual patches and pre-fire vegetation composition. The pre-fire overstory composition of live residuals was compared to the composition of randomly located residual boundaries (polygons of similar size and shape) to determine whether certain vegetation types occurred in residuals in greater amounts than expected. Results indicate that the proportions of deciduous and mixedwood (deciduous and coniferous) overstories found in residuals were significantly higher than expected. The proportions of white spruce dominated overstories and muskeg were also present in residuals in greater amounts than expected, although slightly less than deciduous or mixedwood.

4.0 COMPARISON OF SOIL NUTRIENTS BETWEEN WILDFIRE AND HARVEST STANDS

Jinggang Xu, Paul Yeung, and Philip Lee

Abstract

This study examined the impact of wildfire and harvest on soil nutrients within a retrospective chronosequence of wildfire- and harvest-origin sites. Analysis was focused primarily on sites belonging to the Luvisolic order and Gray Luvisol great group. The early succession of wildfires exhibited an increasing concentration of carbon in the LFH while harvest sites exhibited a declining concentration. Both NH_4 and NO_3 concentrations declined between the one-year-old and 14-year-old wildfire sites, however, concentrations increased by 28 years. In harvest sites, the concentration of NH_4 was equivalent to wildfire sites immediately after disturbance but declined steadily with increasing site age. In wildfires, P concentrations in the LFH and mineral soil declined steadily from one to 28 years, while only P in the mineral soil declined in harvest sites. P concentrations in the LFH remained constant through early succession.

5.0 COMPARISON OF SOIL MICROBIAL ACTIVITY AND NUTRIENT CYCLING AFFECTED BY WILDFIRE AND HARVEST

Jinggang Xu and Paul Yeung

Abstract

Wildfire and harvest may have different effects on the biological properties of soil, which in turn, influence soil nutrient availability and tree regeneration. This project studied microbial activity and nutrient cycling in soils collected from post-wildfire and post-harvest sites of three different ages (1, 14 and 28 years). Results indicated that biological activities and nutrient cycling rates in soil were reduced by wildfire, but tended to recover over time. Conversely, biological activities and nutrient cycling rates in soil were increased immediately post-harvest, but decreased as sites moved through early succession.

6.0 EARLY CHANGES IN RESIDUAL MATERIALS IN ASPEN-DOMINATED WILDFIRE AND HARVEST STANDS

Philip Lee and Susan Crites

Abstract

This subproject focused on the dynamics of residual trees, snags, and downed woody materials (DWM) along a retrospective chronosequence of aspen-dominated (Populus tremuloides Michx) wildfire and harvest (5-6% residual) sites aged one to 28 years. Wildfires produced a series of pulsed inputs of deadwood materials over the first 28 years of succession. Not surprisingly, densities/volumes and decay profiles of snags and DWM of wildfire and harvest sites exhibited their greatest differences immediately after disturbance. Consumption of the forest floor by wildfires resulted in lower amounts of DWM than in pre-burn sites. Fire killed >95% of trees, thereby producing a large initial pulse of snags. By 14 years, many of these snags had fallen, resulting in a pulse of DWM. In contrast, harvest sites exhibited an initial pulse of DWM produced by on-site timber processing. In general, this material was composed of small diameter, or decayed and unmerchantable, logs. As the site developed this initial DWM pulse declined. Subsequently snags and DWM were recruited from the mortality of trees left at harvest. Despite early successional differences, wildfire and harvest sites were converging in the densities/volumes and decay profiles of deadwood by 28 years. Despite the convergence, significant differences still existed in the volume of DWM between wildfire and harvest stands. It was unclear whether wildfire and harvest sites would become identical. Changes of deadwood resources were largely due to the loss of the "biological legacy" associated with each disturbance type and the influences of post-disturbance regeneration. Retention of pulp-merchantable ($\geq$10 cm DBH) and undersized non-merchantable trees at harvest were important factors in speeding the convergence of deadwood trajectories between wildfire and harvest sites.

7.0 DECIDUOUS REGENERATION ONE YEAR FOLLOWING WILDFIRE AND HARVEST IN ASPEN-DOMINATED MIXEDWOODS OF NORTH-CENTRAL ALBERTA

Dan A. MacIsaac and Susan Crites

Abstract

The objective of the deciduous regeneration subproject of the Fire and Harvest Residual Project was to determine the differences in deciduous regeneration between burned and harvested two-year post-disturbance stands. Furthermore, to relate this response to observed stand and microsite conditions as well as to determine the ecological differences between the two disturbance regimes, in order to explain regeneration differences. Regeneration and microsite conditions were sampled in 10 m^2 plots from three harvested and three fire-origin stands in north-central Alberta.

Aspen suckers comprised 68% and 99% of the deciduous regeneration in the harvested and fire-origin stands, respectively. Aspen density was significantly higher in the fire-origin stands (99,470 stems ha^{-1}) compared to the harvested stands (13,010 stems ha^{-1}), whereas average height was slightly greater in the harvested stands (103.5 cm *vs* 93.6 cm). These differences are related to the different ecological processes that follow as a consequence of the two disturbance types. Regeneration was not uniform between the three stands of fire and harvest-origin, due to differences in site conditions between the different stands. The microsite factors of moisture, slope position and disturbance type had a significant and clear effect on regeneration response. High moisture and lower slope position combined to impede suckering as did the surface disturbance and compaction associated with roads and landings. Conversely, the effects of aspect, slope angle, distance to residual, slash and downed woody material had a negligible effect on regeneration.

In spite of the different disturbance modes, most of both the harvested and fire-origin stands have a good probability of meeting the new deciduous regeneration standards at year five. The two areas where the regeneration may not be sufficient to meet the establishment survey standards would be insufficient stocking in the harvested stands (especially H951) due to heavy grass competition, and height growth below the acceptable minimum of 80 cm in the fire-origin stands, due to too much shading by the high number of residual snags. However, it is expected that most of these stands should meet required regeneration standards by year five.

8.0 A COMPARISON OF EARLY SUCCESSIONAL UNDERSTORY PLANT COMMUNITIES FOLLOWING FIRE AND HARVESTING

Susan Crites

Abstract

Early successional understory plant communities were examined in 21 post-fire and post-harvest stands that were one, 14, 28, and 60 years post-disturbance. Understory herbs and shrubs were sampled using percent cover estimates and values were compared using canonical correspondence analysis. Shrub cover, shrub and herb species richness, and species diversity were higher post-harvest than post-fire for the one, 14, and 28 year old age classes, but the reverse was true at 60 years. Due to shading by the shrub layer, shrub cover was inversely related to herb cover. Species composition and abundance were different for each age and disturbance type. One-year post-fire stands were the most unique in species composition and abundance, while 14-year post-harvest and 28-year post-fire stands were most similar in species composition and abundance. The post-harvest plant community was not set back to time zero immediately following harvesting. Instead, shrubs responded to increased light levels and became prolific. The post-fire plant community, on the other hand, underwent a successional trajectory that included early successional fire-dependant species, followed by a shrub community dominated by willow. The successional trajectory post-fire was defined by more dramatic plant community changes than was the trajectory post-harvest. The plant communities at 60 years post-disturbance did not consist of the same species and relative abundances; however, the communities were more similar at 60 years than they were at one, 14, and 28 years post-disturbance.

9.0 ASSEMBLAGES OF VASCULAR PLANTS ON TREEFALL MICROSITES WITHIN ASPEN-DOMINATED BOREAL FORESTS

Philip Lee and Kelly Sturgess

Abstract

This subproject examined the impact of downed logs, stumps, and root throws on the understory composition of aspen-dominated boreal forests. Measures of microsite coverage and suitability, and vascular plant composition and abundance, were taken from matched 28-year-old wildfire and harvest sites. Larger (≥20 cm dia.) downed logs in advanced decay stages were the most suitable for colonization by vascular plants. Suitable downed logs covered more than 5x the area of stumps and root throws combined. Detrended correspondence analysis revealed that logs and stumps were colonized by a significantly different assemblage of vascular plants than the forest floor of either wildfire or harvest sites. Contrary to most of the current literature, assemblages of plants on root throw pits and mounds were not different from the assemblages on the forest floor of either wildfires or harvest sites. Initial colonization patterns on logs and stumps in both wildfire and harvest sites were similar. However, as logs and stumps decayed, assemblages of vascular plants diverged and became more similar to their respective wildfire or harvest forest floor assemblages. Ordination plots of species scores suggested that seed-initiated trees and vegetatively-initiated shade-tolerant herbs disproportionally colonized logs and stumps. These results indicate that logs and stumps play an important role in determining the understory heterogeneity and succession in aspen-dominated boreal forests.

10.0 CHANGES IN BIRD COMMUNITIES WITHIN BOREAL MIXEDWOOD FOREST DURING THE FIRST THIRTY YEARS: CONTRASTING THE EFFECTS OF HARVEST AND WILDFIRE

In Press Ecological Applications 1999

Keith A. Hobson and Jim Schieck

Abstract

A current paradigm in conservation biology is that forest harvest practices that better approximate natural disturbance processes are more likely to conserve biodiversity. We contrasted bird communities in three replicate stands in each of one-year-old, 13- to 15- year-old, and 22- to 28-year-old forests following wildfire and harvest in north-central Alberta, Canada. Stands originated from old (>120 yr) boreal mixedwood forests having at least 95% of the canopy trees killed during fire, and harvested sites retaining an average of 6% of the pre-harvest canopy trees. For all age classes, post-harvest sites tended to have greater bird abundance. Species composition also differed between these treatment types. Two-Way Indicator Species Analysis (TWINSPAN) identified 5 major ecological groupings of species that differed between wildfire vs harvest and among stand ages. Correspondence Analysis (CA) identified similar bird communities. Greatest differences between bird communities occurred immediately following disturbance and gradual convergence of communities occurred throughout the first 28 years post disturbance. Species associated with open shrub and grassland or riparian habitats were associated primarily with one-year post-harvest stands. Three-toed (*Picoides tridactyla*) and Black-backed (*P. arcticus*) woodpeckers, together with other species that use snags for foraging or nesting occurred primarily in one-year post-wildfire stands. Convergence in avian communities was correlated with the loss of standing snags on post-wildfire sites. However, differences in bird communities were apparent up to 28 years following disturbance and this lack of complete convergence has important consequences for sustainable forestry practices designed to maintain biodiversity in the boreal mixedwood forest. Notably, Connecticut Warbler (*Oporornis agilis)*, Brown Creeper (*Certhia americana)*, Winter Wren (*Troglodytes troglodytes)*, and American Robin (*Turdus migratorius)* had higher densities on post-wildfire than on post-harvest stands. Lincoln's Sparrow (*Melospiza georgiana*), Alder Flycatcher (*Empidonax alnorum*), Tennessee Warbler (*Vermivora peregrina*), Black-and-white Warbler (*Mniotilta varia*), American Redstart (*Setophaga ruticilla*), Mourning Warbler (*Oporornis philadelphia*), Rose-breasted Grosbeak (*Pheucticus ludoviciana*), Canada Warbler (*Wilsonia canadensis*), and Pine Siskin (*Carduelis pinus*) had higher densities on post-harvest stands, possibly due to

the greater abundance of larger live residual trees and a taller and more dense shrub layer post-harvest. Harvest designed to approximate stand-replacing fires may require the retention of more snags than currently practiced. New approaches to fire salvage logging are also required to ensure adequate retention of standing dead trees on the landscape.

11.0 BIRD COMMUNITIES ARE AFFECTED BY AMOUNT AND DISPERSION OF VEGETATION RETAINED IN MIXEDWOOD BOREAL FOREST HARVEST AREAS

In Press, Forest Ecology and Management 1999

Jim Schieck, Kari Stuart-Smith, and Michael Norton

Abstract

We evaluated bird community response to type, amount, and dispersion of trees, snags, and shrubs that were retained at harvest in mixedwood boreal forests of Alberta, Canada. We also evaluated whether the degree of similarity between bird communities in harvest and old-growth areas was related to the type and amount of materials retained at harvest. We combined data from three separate studies to generate a large data set covering a wide range of cut-block structures. Birds were surveyed using point counts and line transects. Residual vegetation was surveyed partially on the ground, and partially from aerial photographs. Bird species commonly associated with parkland and open country habitats had high densities in harvest areas that contained abundant shrubs and few residual trees or snags. Within harvest areas where more trees, particularly large deciduous trees, were retained, and when those trees were retained in clumps, bird communities were more similar to those found in old-growth forests. Thus, by retaining clumps of large trees and snags in harvest areas managers may be able to create habitats that are used by old-growth forest bird species. However, for many forest birds, density was lower in cut-blocks with residual trees and snags than it was in old-growth forest. Results should be interpreted cautiously because survival and reproductive success of forest birds in cut-blocks with residual trees and snags was not determined.

12.0 BIRD COMMUNITIES WITHIN RESIDUAL LIVE TREE PATCHES FOLLOWING FIRE AND HARVEST IN MIXEDWOOD BOREAL FORESTS

Jim Schieck and Keith A. Hobson

Abstract

Small residual patches of live trees retained in harvest areas may contain similar biota as found in small "skips" within fires. If the patches/skips are large enough, they are expected to contain many of the biota found in old forests. In addition, as new trees grow around the patches, biota in both habitat types are expected to become more similar to that in old forests. We surveyed birds within residual tree patches in each of four age classes (2, 15, 30, and 60 years) post-fire and post-harvest, and within old (> 120 years) mixedwood boreal forests in central Alberta, Canada. In all habitats we surveyed a range of patch sizes from 0 to > 5000 residual trees. We compared bird communities among patch sizes within each of the eight habitat types, and between disturbance types for each of the four age categories. In addition, within each habitat type we evaluated whether large residual patches had bird communities more similar to those in old forest than did small residual patches.

Species composition differed between patches in post-fire and post-harvest habitats, with the greatest differences occurring immediately following disturbance. Within six of the eight habitat types that we surveyed (patches within age classes 2, 15, and 30 years post-fire and post-harvest), large patches had bird communities that were more similar to those from old forest than did small patches. Within small patches 60 years post-fire and post-harvest, bird communities were most similar to communities found in old deciduous forests whereas bird communities in large patches 60 years post-disturbance were most similar to those found in old white spruce forests. Differences in bird communities between these small and large patches likely resulted from deciduous trees in the patches dying and falling after the patches were created. Following both disturbance types, bird communities in small patches became more similar to old forest bird communities over time. In large patches, however, bird communities became more similar to those in old forest during the first 30 years and then were less similar to old forest at 60 years.

Bird species associated with open shrub and grassland habitats were found primarily within 2-year-old post-harvest habitats. Woodpeckers, together with other species that forage or nest in large snags, occurred primarily in 2- and 15-year-old post-wildfire habitats. Most of these initial differences between post-fire and post-harvest bird communities disappeared by the

time the forest was 30 years old. Convergence was due to bird species that specialize on dead trees disappearing from post-fire forests over time as snags fell. Also, open country bird species disappeared from post-harvest forests as the new cohort of trees grew. Birds associated with young forests became common in both disturbance types as new trees grew around the patches. Most of the birds that are common in old forest were also common in and around patches 60 years post-fire and post-harvest. However, density of birds was lower in patches within 60-year-old forests than in old forests, and many of the uncommon old forest bird species were not detected in and around 60-year-old patches. We did not evaluate the survival and reproductive success of birds within patches and thus viabilities of bird populations in these patches are not known.

13.0 MAMMAL DIVERSITY IN WILDFIRE AND HARVEST STANDS OF ASPEN-DOMINATED MID-BOREAL FOREST

Lui Marinelli

Abstract

Species and animal abundance were used to assess the response of mammal diversity to natural and man-made disturbances in aspen-dominated stands in the mid-boreal forest of Alberta. Medium- and large-sized mammals were enumerated by scat survey in spring, while live trapping was used for small mammals in autumn of 1996. Overall, biodiversity did not differ significantly between wildfire and timber-harvested stands, regardless of the time since the disturbance. Through early succession, the change in the mammalian community differs between the two disturbances types. Communities were dissimilar immediately following both disturbances, but became more similar over time. The diversity index tended to be greater in harvested than wildfire stands. The majority of variables that differentiate wildfire and timber-harvest stands did not appear to be important in structuring the mammalian communities. Snag density was the only significant variable, but explained 5% of the variation in mammalian community. Each species reached their highest abundance in the forest type expected. Rodents tended to be found in recently disturbed stands, while snowshoe hares were more common in older stands. The only disturbance-related phenomenon was snowshoe hares returning to disturbed stands sooner in timber-harvested rather than wildfire stands, presumably due to the lack of cover in wildfire stands. At the stand level, the age of the stand and not disturbance type appeared to be the better predictor of species assemblage for the mammalian community in aspen-dominated stands in the mid-boreal forest of Alberta.

14.0 RODENTS AND RESIDUALS: THE SMALL MAMMAL RESPONSE TO DOWN WOODY MATERIAL IN WILDFIRE AND TIMBER HARVEST STANDS IN THE MID-BOREAL FOREST OF ALBERTA

Lui Marinelli

Abstract

I documented the behavioural and numeric response of three rodent species to varying amounts of down woody material (DWM) in two ages (one and 28 years) of aspen mixedwood boreal forest stands in Alberta following wildfire and timber harvest. Fluorescent powders were used to document trail dynamics and burrow selection, while abundance was assessed among stands using mark-recapture in spring and autumn of 1997 and 1998. The subset of stands from the FaHR project used in this study did not differ in the volume of DWM in the one-year-old wildfire and harvest stands, but 28-year-old wildfire stands had significantly more DWM than harvest stands. Trail lengths and abundance did not vary with volume of DWM when compared between disturbances. However, when disturbance history was disregarded, the average trail length for rodents in one-year-old stands tended to be positively correlated with volume of coarse DWM, and was significantly positively correlated in 28-year-old stands. Animal abundance did not vary consistently with coarse DWM. In one-year-old stands, abundance was greater in spring in stands with more DWM, but the pattern was reversed in autumn. In 28-year-old stands, the positive correlation was found in the stands with low and medium levels of coarse DWM, but the stand with the greatest volume had the fewest rodents in spring and autumn. Burrow locations were almost exclusively associated with structure elements (e.g., DWM, snags, slash piles), with less than 1% located in the ground with no associated cover. Redback and meadow voles selected primarily DWM and standing dead wood to locate burrows and avoided slash piles. Deer mice did not discriminate among burrow locations, selecting equally among the different types. These results demonstrate dependence by boreal forest rodents on residual elements, primarily on DWM. Management in the aspen mixedwood boreal forest results in a DWM deficit, which will be exacerbated if repeatedly harvested. Accordingly, management of small mammals will require management of a number of non-merchantable elements of the forest such as DWM.

15.0 GENERAL DISCUSSION

Philip Lee, Susan Crites, Lui Marinelli and Jim Schieck

The early development of vascular plant, bird, and mammal communities following wildfire differed from those following harvest. Associations between communities and forest structures, however, varied depending on species or guild. No single structural component, species guild, or species could be separated from the rest as being a key element whose management would act as an umbrella for all other structures or species. Indeed, many forest structure elements such as deadwood had varying impacts depending upon stand age, form, and the co-occurrence of other forest structures. In general, this finding points to the value of studies that focus on multiple forest attributes and taxa, and the importance of coarse-filter management strategies.

Despite relying on different forest attributes, the successional trajectories of vascular plants, birds, and mammals exhibited two very similar broad trends. First, all communities exhibited significant convergence in composition and abundances of species within the first 28 years of succession. However, there were no exact matches and, in some cases, converging successional trajectories may diverge again after 28 years. Differences in communities were largely due to differences in the relative abundance of each species rather than changes in membership. The exceptions to this rule were the introduction of weedy and exotic plant species in harvest stands and fire-dependent plant species in very early successional wildfire sites. A more directed study dealing strictly with rare species may find different results.

A second general result was the uniqueness of early wildfire communities. The dramatic differences in habitats immediately post-wildfire supported altogether different assemblages of species. In particular, vascular plant and bird communities were dominated by species which were uncommon or rare in older wildfire and all harvest ages. Given the complexity of forest attributes co-occurring immediately after wildfires, it is unlikely that harvest could ever feasibly produce such attributes.

Forest Structure and Canopy Development

Dominant vertical features of wildfire stands included the removal of most of the understory vegetation and the near instantaneous creation of hundreds of snags per hectare. After a fire, most of the trees were killed but remained standing with canopies relatively intact. The spatial distribution of snags was largely determined by their pre-disturbance distribution of trees. In contrast, the pattern of above-ground structure in residual cutblocks (~ 6% merchantable leave volume) consisted predominantly of live vegetation. The tree component was a variable mix of undersized trees, seed trees, and

merchantable tree retention. In many ways, one-year-old cutblocks with residuals visually resembled parkland habitats. That is, a scattering of single trees and patches of trees in a matrix of grass, low herbs, shrubs, and regenerating trees.

With the falldown of snags and the regeneration of trees, the vertical structure of wildfire stands changed very quickly in the first 28 years. The early succession of wildfire stands exhibited a very high fall down of fire-killed snags. Our results indicated that density of snags declined 25 to 30x in the first 28 years. During this decline, the physical structure of snags changed; tall, hard, well-branched snags gave way to shorter snags with broken tops, multiple soft spots, and cavities. In contrast, the density of snags increased slowly within harvest stands. The few snags left at harvest were supplemented by the mortality of residual trees. The provision for a range of tree sizes at the time of harvest provided for continual snag recruitment over the early part of succession. Without leaving trees at harvest, the few snags left at harvest would fall within a relatively short time. The density of snags would likely not match the density within wildfires until the death of large trees ($\geq$20 cm DBH) from the regenerating cohort of trees. This will not likely occur until cutblocks are >50 years old.

Despite higher densities of aspen regenerating after wildfires, these stands had a more rapid loss of stems from self-thinning. Many of the stems had lower than average heights post-fire. It was estimated that at least 30% of them would not be alive the following year. This will, in all likelihood, allow the regeneration densities in post-harvest stands to match those of post-fire stands over time and should not have major effects on yields at rotation age (~80 years) (Bates et al. 1989). Our data indicated that the densities of regenerating trees were similar between burned and harvested stands at 14 and 28 years of age.

With the regeneration of trees, the vertical structure of both wildfire and harvest stands became two-tiered. Initially, wildfire stands had a relatively regular distribution of tall snags (20-25m) with a dense understory of regenerating aspen. As the stands aged, the density of snags decreased while the live canopy increased in height. At 28 years, stands had a low density of snags with an 8-12m live canopy. Due to wind-snap, many of the snags lost their tops and were similar in height to the regenerating trees. Harvest stands had a different vertical and spatial structure. As already described, structure in early harvest stands consisted predominantly of single or patches of trees. Patches of canopy tree residuals formed the uppermost layer while the neighboring regenerating trees formed a lower layer. As harvest stands developed, the larger patches of residuals continued to age and attained old growth characteristics such as increase in gap dynamics, development of canopy veterans, and recruitment of a secondary

cohorts of trees. By 60 years of age, patches and cutovers were the same height.

As with the vertical structure, initial forest floor components were very different among wildfire and harvest stands. Initially, wildfires had lower amounts of downed woody material (DWM) on the forest floor through consumption by burning. Stand replacing fires in aspen tend to be ground fires and are dependent upon the consumption of forest floor fuels, often producing smoldering and charcoaling of even large diameter DWM (Quintilio et al. 1991). Wildfires of moderate to high severity may mineralize large amounts of living and dead organic biomass on the forest floor creating a flush of nutrients (Woodmansee and Wallach 1981). The pulse of snags created by wildfires was transformed into DWM within a few years after disturbance. After 14 years, we recorded a slow decline of DWM. The decline produced an increase of carbon concentration in the soil organic layer.

In contrast, harvested sites had an input of DWM from the on site-processing of trees, i.e., removal of butt ends and tops, branches, and incidental damage and falldown of whole trees. As the post-harvest stands aged, the only source of large DWM input was from falldown of large residual trees and snags. Harvested stands exhibited a decline in DWM volume to 28 years. After 28 years the differences between wildfire and harvest declined, but DWM volume within harvested stands was still lower. It is unlikely that harvested stands would begin to accumulate large pieces of DWM until 50-60 years stand age. Given rotation ages of 70-90 years for aspen-dominated boreal forests, this strongly suggests that repeated cycles of timber harvest will decrease both the deadwood structural component and soil carbon within aspen-dominated boreal forests. Although the impact of these components may not be as initially dramatic as the vertical structure, successive cycles of harvest could potentially lead to serious changes in biodiversity. The loss of deadwood resources has been the legacy in other boreal forests with longer histories of successive harvest (Haapanen 1965; Berg et al. 1994; Rydin et al. 1997; Ostlund et al. 1997; Linder and Ostlund 1998).

Vascular Plant Communities

Vascular plant communities exhibited staggered successional trajectories with wildfire stands undergoing a different trajectory than harvest stands. Succession of wildfire communities were more dramatic than harvest communities. The wildfire trajectory included early successional fire-dependant species, followed by a shrub community dominated by willow. The one- and 14-year-old wildfire communities were very different from older wildfire and harvest communities. By comparison, harvest stands exhibited smaller degrees of change from stand initiation to 28 years. Communities within one-year harvest sites had a high degree of overlap with plant communities of older aged sites. This trend continued in older stands with 14-year

harvest sites having very similar communities to 28-year wildfire sites. These results emphasized the disparate origins between wildfire and harvest stands, resulting in a different successional pathway for each subsequent plant community.

Differences in the species composition and abundance could be directly correlated to the biotic and abiotic conditions associated within the different ages of each disturbance type. Early successional development of wildfire stands was dominated by a number of fire-dependent species including *Geranium bicknellii*, *Corydalis sempervirens*, and *Dracocephalum parviflorum*. These species were rare at other stand ages and following other disturbance types. It was likely that the unique combination of conditions immediately post-fire, i.e., soil nutrients released from biomass burning, blackened soil, increased temperatures and light, and release from forest floor competition, make conditions suitable for germination of previously dormant seeds. Other species present pre-fire were also present post-fire but their ability to re-sprout was dependent on their tolerance to light and fire severity (Brown and DeByle 1987).

In comparison, communities within harvest stands were not set back as far as wildfire stands after disturbance. A number of species, including grasses and shrubs, responded to increased light levels and flushes of available nutrients, thus becoming dominant. Harvest activities created a greater diversity of microsites, which may have allowed many species to persist and become prolific. Many of these species were similar to understory communities in older aged sites, a result of the residual patches left after harvest.

Succession beyond the early stages was increasingly dominated by the development of the canopy layer and the subsequent decrease in light reaching sub-canopy layers. Both disturbances saw the continued reduction of shrub cover from 28- to 60-year-old stands. Herbaceous cover responded by decreasing when shrub cover was high, and increasing when shrub cover was reduced. Although older wildfire and harvest communities were more similar, the lag effect of succession seems to have changed. If time were the only factor causing differences between plant communities, the 28-year-old harvest sites should be similar to the 60-year-old wildfire sites. Instead, 60-year-old wildfire community remained closer to the 14-year-old harvest and 28-year-old wildfire communities than to older harvest sites. This suggests that convergence during early succession could lead to divergence in later development. A number of forest attributes could account for the change in convergence trends. One possibility is the lingering influence of the downed woody material on the post-fire sites. This wood may serve to mitigate some of the dramatic changes after wildfire by serving as safe sites for understory plants and providing nutrients and organic matter to the site. Another

factor is the succession within patches left at harvest. Understory in these areas would be older than wildfire stands and may facilitate an earlier shift to older successional communities in harvest stands.

The wildfire and harvest plant communities were more similar at 60 years post-disturbance than they were initially, but at 60 years there were still differences in species composition and abundance. The plant community post-fire underwent a different successional trajectory than the plant community post-harvest. These different trajectories were still apparent 60 years post-disturbance.

Bird Communities

The successional pattern in the bird community was similar to that detected in the vascular plant community. The greatest differences between bird communities occurred immediately following disturbance with gradual convergence of communities occurring throughout the first 28 years afterwards. Bird communities responded in a very predictable manner to differences in the vertical structure of stands from different ages and disturbance types. Communities in one-year-old wildfire stands were dominated by species that nest and forage in large snags. Some species found in these stands such as Black-backed and Three-toed Woodpeckers are relatively rare in old stands. Compared to wildfire stands that are dominated by snags, early successional harvest stands have a patchy distribution of residuals in a matrix of open areas. As such, the bird community present in one-year-old harvest stands included species that typically nest and forage in open grass or shrubby habitats (e.g. LeConte's Sparrow, Clay-colored Sparrow).

Even though the gap between wildfire and harvest communities had been reduced by 14 years, there remained significant differences. Species preferring to nest and forage in large snags, such as Hairy Woodpecker, Northern Flicker and Tree Swallow, exhibited higher densities in 14-year-old wildfire stands. In contrast, species that prefer to nest or forage in closed-canopy forests (i.e. Rose-breasted Grosbeak) had higher densities in 14-year-old harvest stands. Continuing convergence of wildfire and harvest bird communities from 14 to 28 years was largely due to changes within the wildfire bird community. Bird species that nest and forage in large snags declined in abundance, whereas those species requiring a well-developed shrub layer maintained or increased in abundance.

The absence of complete convergence in bird communities after 28 years may be related to remaining differences in shrub density, vertical structure, amount of ground cover, or abundance of large, live residual canopy trees. Similar to the response of vascular plants, the residuals within the 28-year-old harvest stands may have produced stands bearing some attributes more typical of old seral stages. Species typically

associated with shrubby areas within old-growth forest such as American Redstart and Canada Warbler, had higher densities in the 28-year-old harvest stands.

Mammal Communities

Mammal communities were characterized by fewer species than either plant or bird communities. All common mammal species were present in both stand types and at all stand ages, except snowshoe hares. Differences amongst disturbance types and stand ages were expressed as differences in the relative abundance of species. Like other taxa, the greatest dissimilarity between communities occurred immediately following disturbances, and communities became more similar over time. The animal abundance of one-year-old wildfire and harvest stands was very different from each other with the harvest stand being more similar to 14-year-old wildfire stands. Younger harvest stands tended to be similar to older wildfire stands. The 14-year-old and 28-year-old harvest stands overlapped with each other and with the 28-year-old wildfire stands. This suggested that the harvest stands entered a similar successional trajectory as wildfire stands but at later stages of development.

A number of the dominant variables that differentiate the structure of wildfire and timber-harvest stands did not appear to be important in structuring mammalian communities. Snag density was the only significant variable, but explained 5% of the variation in the mammalian community. More subtle aspects of forest structure were associated with species abundance. The structure of the forest floor and types of plants in the understory were the most important determinants of mammalian abundance. Meadow voles and deer mice were found primarily in newly disturbed wildfire and harvest stands. These species are primarily associated with an increase and domination of grasses in the understories of these stands. Accordingly, it is not surprising that the short-tailed weasel, a predator of deer mice and voles, also reached their highest abundance in the same habitat. Redback voles were ubiquitous to all stand types and ages.

In contrast, snowshoe hares were not found in newly disturbed stands, likely due to a lack of cover. Snowshoe hares reappeared in 14-year-old harvest stands but not wildfire stands. The falldown of snags and the resultant physical barrier of logs, particularly elevated logs, on the forest floor may have prevented the passage of snowshoe hares during the winter. Twenty-eight years following wildfire, the logs have degraded sufficiently such that they are closer to the ground, making the stand more suitable to hares. At that time, we see a rise in the density of snowshoe hares in wildfire stands. Four species of shrews were captured; the majority of which were masked and dusky shrews. Shrews are dependent on insects in the summer months as their primary source of food (Getz 1961; Banfield 1974). DWM of advanced decay

stages harbour a variety of insect species (Irmler et al. 1996; Torgersen and Bull 1995). Correspondingly, shrews reached their highest abundance in mature to older stands (i.e., 14- and 28-year-old stands), where the median decay stage of DWM was greater than in newly disturbed stands. The overall conclusion of the mammal surveys suggested that the age of the stand and not disturbance type appeared to be a better predictor of species assemblage.

Rodents demonstrated a dependence on forest residuals primarily by locating the vast majority of their burrows in downed or standing dead wood. Redback and meadow voles selected primarily DWM and standing dead wood to locate burrows and avoided slash piles. Deermice did not discriminate among the three burrow locations. Because of the numeric superiority of redback voles in all stages of succession in the boreal forest, the lack of use of slash piles would suggest an alternate use of harvesting debris. As opposed to piling the slash, redistribution in the stand would provide a greater amount of DWM for redback voles to utilize. The redistribution would provide temporary compensation for the DWM deficit created in harvested stands. The effect would be temporary as the majority of the slash is small in diameter and is quickly reduced to soil by the decay process. However, the redistribution and potential benefit to redback voles must be balanced against the potential negative affects on aspen regeneration.

The pattern of DWM between wildfire and harvest stands did not show correlation with rodent abundance or behaviour. This result may be, in part, due to the selection of stands. A subset of the study sites was used to analyze the response of rodents to DWM. Among these stands the pattern of change in DWM relative to disturbance history was not the same as that documented when all stands were considered. However, when stands were organized based on volume of DWM and not disturbance history, a clearer behavioural correlation was evident. The length of rodent trails tended to be positively associated with volume of DWM in stands one year post-disturbance. The relationship was positive and significant 28 years post-disturbance. Animal abundance did not vary consistently with the volume of DWM. In one-year-old stands, a positive correlation between animal abundance and volume of DWM in spring was contrasted by an opposite relationship in autumn. Among the older stands, a positive correlation was found with low and medium volumes of DWM, but the stand with the greatest volume had the fewest rodents in spring and autumn.

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16.0 MANAGEMENT IMPLICATIONS

Philip Lee, Susan Crites, Lui Marinelli and Jim Schieck

Live residuals provide a continuing source of advanced forest structure into stand development

Few if any forest managers take seriously the notion that the relatively few live and dead materials left at harvest "mimics" the structures after wildfires. The major difference is the surrogate use of fewer, predominantly live residuals within harvest stands for large quantities of dead residuals within wildfire stands. However, the strategy of using live residuals allows for a continued recruitment of this material into critical large tree and deadwood categories during stand development.

Within structured cutblocks, smaller residual trees have the opportunity to recruit into larger size categories. Residual trees grow and eventually die producing large snags and DWM. Depending on the size distribution and density of residual trees, this process can significantly continue into stand development. In contrast, most of the vertical residuals in wildfire stands are dead. Although initial snag densities in wildfire stands are much higher, densities will decline until stands are 28 to 50 years in age. Residuals from wildfire have a very large initial impact that declines over time, whereas residuals from harvest have a relatively small initial impact that increases during early and mid-successional development.

Increasing the density and size distribution of residual trees in harvest areas likely decreases the time to convergence with natural wildfire stands. Although, this study did not vary the amounts of residuals, we detected a recruitment pattern that strongly suggested that greater amounts of trees at harvest would lead to greater densities of snags earlier in development of harvest stands. In turn, this would produce an earlier convergence with wildfire stands.

Increasing the amount and patch size of residuals leads to more old stand attributes

At very high levels of residuals (>50 % merchantable volume), the type of wildlife habitat dramatically changed. Rather than very young stands with relatively few patches or single trees in a matrix of grasses, shrubs, and regenerating trees, the habitat becomes more analogous to an open canopy, old growth stand. That is, a cover of large trees with a few open areas analogous to canopy gaps. Chapter 11 compared bird communities studied in this project with two other studies. The results indicated that as the amount of residual trees and snags increased, bird species associated with mature and old boreal forest became more common, and conversely, bird species associated with open country and shrubby areas, i.e. early successional species, became less common. Aside from impacts on bird communities, higher

levels of canopy retention would also mean greater retention of mature and old understories in these stands.

The spatial pattern of residual material can also be varied throughout cutblocks. Larger patches of residuals are more effective at insulating against edge effects, hence, preserving more of the microhabitats present in the forest prior to harvest. Larger clumps were refugia for more bird species than small clumps because some birds require microhabitats found only in large undisturbed areas (see Chapters 11 and 12). Thus, leaving a single large patch within every cutblock would provide the greatest amount of old stand biota in early stand succession after harvest.

However, the danger in this type of strategy is two-fold. First, it removes variation from the landscape. With every block being the same, a narrower range of biota are supported than would be by providing a variety of retention amounts and patterns. Secondly, although scattered smaller patches may not have the same initial impact as large patches, small patches may increase the vertical stratification of the canopy later in stand development. In the long-term, small patches may promote old stand characteristics throughout the entire stand better than a few large patches. Managers could vary the spatial pattern of residual materials among blocks from traditional clearcuts to scattered small patches and single trees, to blocks with a few large clumps. The specific mix of treatment types depends upon the overall landscape strategy desired.

In the end, an appropriate mix of residual patterns across the landscape will be determined by ecological, economic and social considerations. Aside from the economic trade-off of leaving merchantable volume on the stand, other considerations include worker safety, machinery limitations, operator training, post-harvest assessment, suppression of regeneration and soil compaction.

Protection of wildfire communities requires some protection from salvage logging

The most unique communities in this study were found in the one-year-old wildfire stands. The communities of vascular plants, birds, and mammals within these stands are all very different from all other communities in all other stand ages and disturbance types. Indeed these communities are even more unique than those associated with old seral stages of aspen forests (Stelfox 1995). Despite the use of a wildfire template for timber harvest, there is no realistic expectation that harvest will produce stands analogous to very early wildfire stands. This leaves wildfire as the only source for producing these stands.

Despite our current efforts in Alberta, catastrophic wildfires still occur relatively frequently on the landscape. The size of area burned by wildfires in Alberta tends to cycle

with considerable variance around 10- to 20-year intervals (Delisle and Hall 1987; Cumming 1997). Hence, the production of wildfire stands tends to be sporadic but massive when it occurs. The ability to salvage all burned stands of commercial value, particularly from catastrophic years, exceeds the current abilities of the industrial sector. Therefore, many wildfire-origin stands not affected by salvage harvest still occur in Alberta. This may not be the case in the future. Increasing sophistication of wildfire protection, fragmentation of fuel blocks, better access, and improved technology for salvage logging, may reduce the availability of natural wildfire communities. That could have major impacts on biota in Alberta's boreal forest. In other fire-dependent forests, the loss of wildfire has produced major disruptions to successional pathways with a resultant loss of unique fire-dependent natural communities (Pyne et al. 1996).

Consideration should be given to a policy of temporarily, but purposefully, setting aside and not salvaging a percentage of stands that burn every year. These stands should be relatively large and contain large trees (>20 cm DBH). The stands would not be taken out of the normal rotation. Assignment to this status would be temporary, lasting only 15 or 20 years after burning. After that time, the stands could return to the harvested landbase.

Harvest potentially leads to a reduction of deadwood resources and soil carbon with an ensuing decline in biodiversity

Deadwood resources are a significant feature of all forested ecosystems (Harmon et al. 1986). Until recently, deadwood has been seen as a wasteful, even undesirable, component of forests. In part, this view has its roots in wildfire management, worker safety, disease and pest control, and utilization dogma (Hagan and Grove 1999). While all of these are legitimate concerns, the ecological role of deadwood resources must also be addressed.

In forest systems where practices have led to significant reductions in the density and sizes of snags and downed logs, significant losses of wildlife have occurred. Elimination of large snags from the Sierra Nevada forests of western United States and Finland has reduced the abundance of cavity-nesting birds by 77% and 44%, respectively (Haapanen 1965; Raphael and White 1984). In Sweden, losses of deadwood has been one clear impact of long-term timber harvest (Ostlund et al. 1997; Linder and Ostlund 1998). Of threatened species in Sweden, 21% were linked to snags (n~312 species) while 26% were linked to logs (n~390 species) (Berg et al. 1994). Lowered quantities of snags and downed logs eventually work their way through the ecosystem, producing reduced inputs of carbon into the soil (Minderman 1968). These losses are part of an ongoing discussion about overall

losses of nutrients in repeatedly harvested forests (Maser and Trappe 1984; Dutch 1993).

After 28 years, difference in DWM and soil carbon between wildfire and harvest stands decreased. However, volumes of DWM and soil carbon within harvest stands were still significantly lower than wildfire stands. Large logs (≥20 cm dia.) contribute a significant amount of carbon to deciduous boreal stands (Lee et al. 1997; Slaughter et al. 1998). Large trees will not be available until stands are older. A number of current forestry practices can lead to the potential reduction of deadwood and soil carbon. These include loss of older seral stages through short-rotation logging, pre- and post-commercial thinning, burning of cutovers, and road-side processing. Losses within a single rotation may be relatively small. Nonetheless, if losses compound over successive cycles of harvest and regeneration, deadwood carbon will exhibit a long-term decline.

Solutions to this problem take a number of forms. The losses appear to accrue with time, hence, maintenance of deadwood resources is a long-term management issue. Clearly, the very definition of timber harvest includes the removal of boles from the system. It will be impossible to compensate for all the carbon removed from harvested stands. However, we may be able to extend the rotations on a percentage of stands and maintain a base level of snags, DWM and soil carbon in other stands at levels that support most of the biota associated with these structures. A landscape approach could be taken in managing deadwood resources. Maintenance of deadwood would be set on a regional basis with different areas supplying different habitat needs.

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17.0 FUTURE RESEARCH, ADAPTIVE MANAGEMENT, AND MONITORING

Philip Lee and Lui Marinelli

In part, the impact of harvesting uncouples the development of naturally associated forest structures. As an example, regenerating trees in young harvest stands are likely associated with very few snags. In contrast, regenerating trees in young wildfire stands are tied to a high density of large snags. Taxa vary in their response to forest structures. Some species have very clear, specific relationships with certain forest structures. Other species are more general in their preference of habitats. While even other species have a more complicated relationship with habitat involving other biotic and abiotic factors such as competition, activities at multiple spatial scales, or seasonal variation.

Depending on overall objectives, managers have always tried to manipulate the various aspects of the habitat in an effort to finesse biota into particular patterns and abundances. In this regard, the design of cutblocks presents a particularly bewildering array of choices. Variation in riparian zones, cutblock size, edges, shapes, green up times, residual amounts, residual types, and residual patterns are all being considered or currently practiced. Furthermore, there exists no single optimal cutblock design, rather variability among cutblocks is a desirable feature. Despite the literal explosion in both research and management options, the interface between these two institutions remains elusive. The multiplicity of different features and the effort to evaluate their impacts on multiple taxa presents a formidable task for traditional experimental science. Measurements on multiple taxa groups requires large spatial scales. As an example, measurements on bird communities require stand sizes of at least 35 ha to isolate edge effects. Simultaneous and controlled evaluation of different treatments requires a high number of replicates. Multi-factoral designs are very difficult to achieve given the costs and logistics associated with a large number of field sites. Because forest succession is measured in decades, researchers may be faced with initiating experiments whose full outcomes are not going to occur within their lifetimes. Lastly, the objectives of management often are different than those of scientific experiments. Management objectives are often broader and less specific than those in experimentation. Frequently, managers need to evaluate impacts on collatoral issues that are not directly tested by researchers, such as administrative factors and public response. To each of these design problems, researchers have applied a number of ingenious solutions. However, there remain some areas of difficulty for traditional experimental science.

An alternative to traditional experimentation for some questions is the application of adaptive management. Adaptive management is "a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form, "active" adaptive management, employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed."[1] Though the language is very similar in nature to traditional experimentation, adaptive management differs in being driven by the needs of management rather than an academic interest in cause and effect patterns. In adaptive management, the experimental unit is usually a management unit such as a stand or larger landscape unit. Traditional experimental units are driven by the link between the treatment and response variable. Adaptive management often tests large complex sets of management actions on response variables. The latter are selected largely on the basis of management values.

The use of adaptive management does not negate the importance of traditional research, nor does traditional research substitute for adaptive management. They are complementary activities. Research provides critical knowledge about the fundamental processes driving forested ecosystems. Adaptive management takes this knowledge, makes broad predictions tied to complex management decisions, and applies these experiments on the landscape. Adaptive management is the marriage of research and broad management policy.

A third activity, monitoring, provides key information for both research and adaptive management. For research, broad-based status monitoring provides the early warning that changes are occurring within ecosystems and that the underlying explanations for these changes are worthy of further exploration. Also, experimental results may use monitoring data to extrapolate results over larger land areas and longer time frames. For adaptive management, monitoring provides feedback on the management outcomes and insight into appropriate modifications to management.

On these bases, we define several areas of future work that involve appropriate areas for research, adaptive management, and broad-based monitoring.

[1] Nyberg, J.B. 1998. Statistics and the practice of adaptive management. In: Statistical Methods for Adaptive Management Studies. Eds. V. Sit and B. Taylor. Research Branch, British Columbia Ministry of Forests, Victoria, B.C. Land Management Handbook No. 42. pp. 1-8.

Areas of Research

This is a partial list of research topics that flow from the results and discussion of this project. They are presented in no particular order of importance.

1. **Functional relationships between taxa and residuals** – This study identified a number of relationships between taxa and residual elements. The current research from this and other studies provides a limited list of taxa-habitat relationships. Research should continue further elucidating the relationships between taxa and different forest structures left after harvest. A short-list of important forest structures includes access (roads, skid trails, landing decks), patch composition, patch and cutblock edges, and silvicultural practices.

2. **Impact of post-harvest prescribed burning on herbs and mammals** – For vascular plants and mammals, the initial condition of the forest floor, played a large role in their respective successional trajectories. Prescribed burning offers a potential tool to alleviate some the differences between harvest and wildfire stands.

3. **Impact of salvage logging on succession of forests and biodiversity** – Salvage logging is a common activity after most wildfires. This type of stand-origin has been virtually unstudied in this or any other forest ecosystem. Yet it comprises a large portion of stand origins in the last twenty years in Alberta and most other jurisdictions with significant wildfire activity. Given this, some effort should be made to understand the long-term impacts of further disturbance in wildfire stands by salvage logging.

4. **Modeling the cycle of deadwood resources and carbon in forested ecosystems** – This study like others have demonstrated a short-term and potentially long-term chronic loss of deadwood resources and carbon in harvest stands. The historical impacts on biodiversity and productivity from other systems are quite clear. What is less clear are the long-term implications of particular management actions on the supply of deadwood resources and soil carbon. Research should focus on developing long-term models for carbon flows within stands under different management scenarios.

5. **Expanding the scale of evaluation from stand level to landscapes** – This was a stand-level study. As much as possible we tended to isolate our stands from influences of neighbouring stands. Nonetheless, both wildfires and harvest create landscape patterns. The stands and other landscape features within these larger units are likely to have some influence on each other's development after initiation. It would be

worthwhile, particularly with greater ranging taxa such as carnivores and ungulates, to compare the biota within a wildfire landscape compared to a harvest landscape. In general, the identification and tracking of spatial and temporal patterns at the landscape level remains relatively unstudied.

Adaptive Management

This study identified two management issues that could be evaluated through adaptive management.

1. **Development of overall cutblock design** – This project evaluated a single cutblock element, i.e., residuals. There are many other elements, including riparian zones and access, plus the size and shape of cutblocks, that could be evaluated. It would be expensive and logistically difficult to design experiments to stratify and test all of these factors. Also, factors such as worker safety, economics, and societal values are difficult to integrate. We would suggest that overall cutblock design would be a suitable candidate for adaptive management.

2. **Landscape management patterns** – Rarely can all or even many management objectives be achieved at the stand-level. Instead, objectives are partitioned spatially and temporally over a broad landscape. Like the previous example, the complexity and uniqueness of large landscapes makes adaptive management the preferred method of management. With increases in spatial and time scales, modeling and projection of possible impacts plays an important role in setting policies at landscape levels. Although, smaller units such as cutblocks may meet objectives such as natural disturbance templates. Development or disturbances at the larger scale may serve to undermine objectives at the stand level. Clearly, larger scale effects and their impacts need to be integrated.

Broad-Based Monitoring

A number of factors have been identified, by this project, to be of potential concern. It is unclear at this point in time whether special management action is warranted. However, monitoring as part of status reporting is prudent.

1. **Introduction of exotics and weed species**– Invasion of exotic and weedy species is a common occurrence after initial disturbance of landscapes by human activity. This study found an increase in weedy species after harvest. The shift from a more natural to a semi-natural landscape suggests that invasion of exotics and increases in weedy species will become more common. The potential biological impacts are relatively well known but the extent and rate of

increase of exotics in the Green Zone is poorly understood. The problem is likely to be long-term and incremental in nature. Accordingly, monitoring would begin to provide data on ecological changes associated with the introduction of exotics in the Green Zone.

2. **Deadwood resources and soil carbon –** As already discussed, harvest areas have a short-term and potentially long-term loss of deadwood resources and soil carbon. Broad-scale monitoring provides long-term status reporting for these elements and sounds an early warning of drastic changes. Also, the attainment of carbon credits by industry is likely to be a significant issue. Deadwood resources and soil carbon represent large sinks of carbon that can potentially be applied as credits.

3. **Percentage of young wildfire origin stands –** Young wildfire stands are a unique community. Their maintenance on the landscape is an important element for the sustenance of Alberta's biota. The supply of young wildfire stands should be monitored as part of the important biotic elements within a landscape management package. Our current and future supply of these stands is unclear. Monitoring would be a first step in determining whether more austere methods may be warranted.